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RESEARCH IN WATER SPREADING

By Dean C. Muckel

IRRIGATION DIVISION

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AMERICAN SOCIETY OF CIVIL ENGINEERS

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PAPERS

RESEARCH IN WATER SPREADING

By Dean C. Muckel[1]

Synopsis

To determine the factors affecting the rate of recharge of ground water by means of spreading basins, a program of research and field experimentation was carried on in the San Joaquin Valley, Calif. The results of this research are reported in this paper.

Early studies had determined the percolation characteristics of undisturbed and disturbed soils, and the research of this program checked these characteristics under field conditions. In order to vary the test conditions, two groups of ponds were used, and the effect of factors such as chemical, mechanical, vegetative, and operational conditions were studied. In addition, treatment of the basin surface with organic matter was tested and found to produce good results.

Introduction

The method of water conservation known as water spreading is defined as the practice of diverting water from natural stream channels and spreading it over porous lands, thereby giving it opportunity to sink into the ground and eventually become a part of the main ground-water body. The term water spreading has also been used in some localities to describe the practice of diverting stream flow during flash floods to pasture and other lands for the purpose of irrigation. Although the two spreading systems may be similar in design, their purposes are definitely different. As used in this paper, the term is applied only to the practice of diverting for replenishment of the underground water supplies. Such spreading is used in areas in which pumping from wells is a major means of obtaining water.

Spreading for replenishment of the ground-water supplies involves much greater quantities of water than those required for irrigation. Water is applied to areas in such quantities and for such long periods of time that the

Note.—Written comments are invited for publication; the last discussion should be submitted by June 1, 1952.

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amount of water retained in the root zone is negligible. The purpose of such application is to stimulate percolation, to replenish the ground-water supplies, and to raise the water table, whereas in irrigation an adequate application consists of a few inches per irrigation, or 2 to 4 ft per yr. In spreading for replenishment of ground water, several acre-ft per acre of water may be put into the ground in a single day.

The need for water spreading has been apparent in many localities for many years, and it is of growing importance in others. Pumping from wells has long been the principal source of water in parts of the semiarid West, and since 1930 the demand for water has increased greatly as more land has been brought under irrigation and domestic and industrial uses have been expanded. Other areas throughout the United States have reported increases in the draft on ground-water supplies. More efficient pumping equipment, improved well-drilling methods, and wider distribution of power have accounted for some of the increase. In the East and Middle West, these drafts on the ground water have occurred from demands for domestic, industrial, and other uses, such as air conditioning.

Water spreading was first attempted on a large scale in the south coastal basin of California because conditions there lent themselves well to this type of conservation, and the need for water was great. Areas suitable for spreading exist at the mouths of the many canyons where they debouch from the mountains. The streams have built up relatively steep debris cones by dropping their loads of boulders, gravel, and sands as they struck the flatter slopes of the valleys. Because of the coarse material of which these cones are composed the lands are not particularly suitable for cultivation and are in general classed as waste land. Those areas are porous and have high rates of infiltration and consequently are well adapted to water spreading. Spreading has also been contemplated for recharging of ground-water supplies in other areas. In San Joaquin Valley spreading of flood waters is a part of the Central Valley Water Plan and is also contemplated by local water storage districts. In fact, the North Kern Water Storage District on the Kern River Delta near Bakersfield, Calif., has withheld a large area of valuable agricultural land from cultivation for the purpose of spreading and recharging of the ground-water supplies within its boundaries. Natural spreading areas consisting of waste land and composed of porous soils are practically nonexistent in those parts of San Joaquin Valley needing replenishment and, therefore, spreading must be done on the finer textured soils such as sandy loams and fine sandy loams.

Research Projects

The research work reported in this paper deals with water spreading in the San Joaquin Valley. The problem here was to obtain and maintain a satisfactory percolation rate, whereas on the gravel cones of southern California the problem was primarily one of construction and maintenance.

Early Studies.—Tests started in 1936 showed that the percolation rate decreased below the limit of practicability when water was applied continuously to an undisturbed soil for extended periods. A search of the literature showed that considerable experimental work was being done at that time on the problem

of infiltration, but in nearly all cases the experiments were made in connection with infiltration of rainfall or irrigation water. Consequently, the water was applied for short runs only. In spreading, water may be applied continuously for weeks or even months at a time.

Typical percolation rate curves are shown on Fig. 1. The curve representing undisturbed soils indicates that after a short shut down the curve repeats itself but at a lesser rate. On the basis of work done in the laboratory with

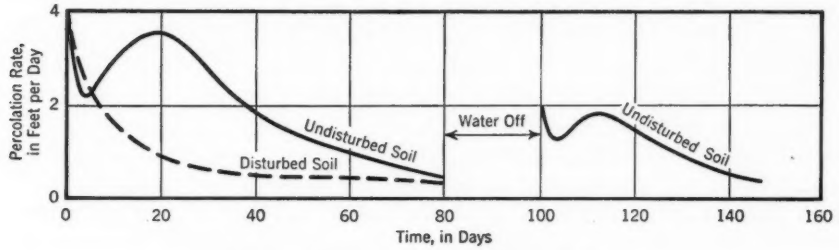

FIG. 1.—TYPICAL PERCOLATION RATE CURVES

soil cores[2] the S-shaped percolation rate curve was explained as follows:

"a. The initial decrease in permeability or infiltration rate is believed to be caused by dispersion and swelling of the soil particles. This is much more pronounced in some soils than others.

"b. The increase in permeability following the initial decrease accompanies the elimination of entrapped air from the soil. This air is slowly dissolved in the water passing through the soil.

"c. The gradual decrease in permeability that follows is due primarily to biological activity in the soil."

The typical percolation rate curve for soil plowed or otherwise disturbed prior to spreading is also given in Fig. 1. In this case, the rate of percolation is apparently controlled at or near the soil surface, and the rate of entrance of water into the soil is less than the rate at which the water would move through the soil profile. Therefore, the entrapped air influence is not effective. Technically, at least a portion of this curve probably represents infiltration rate rather than percolation rate.

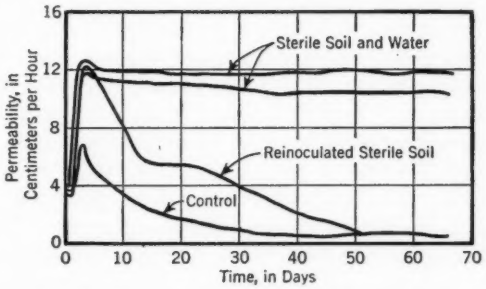

FIG. 2.—PERMEABILITY-TIME CURVES FOR EXETER SANDY LOAM UNDER PROLONGED SUBMERGENCE

The explanation of the S-shaped curve was substantiated later by permeability tests with sterile soil and water. In Fig. 2, note that the permeability

[2] "Effect of Entrapped Air Upon the Permeability of Soils," by J. E. Christiansen, *Soil Science*, Vol. 58, No. 5, November, 1944.

of sterile soil and water was maintained at approximately the maximum rate although the control operated under ordinary unsterile conditions followed the typical curve of Fig. 1. The conclusions from this experiment were:

> "Sterile permeability tests conducted to determine the cause of decrease permeability under prolonged submergence gave no evidence of soil aggregate breakdown due to purely physical causes. The reduced permeability appears to be due entirely to microbial sealing. The soil pores probably become clogged with the products of growth, cells, slimes or polysaccharides. If any of the observed reduction in permeability was due in part to disintegration of soil aggregates, the dispersion is believed to be due to biological causes, that is, the attack of microorganisms on the organic materials which bind soil into aggregates."

There is evidence that these products of microbial activity not only seal the soil during wetting, but also tend to improve the aggregation of the soil upon drying. This aggregation may in turn cause percolation rates higher than the initial rate. In other words, if energy material is added to a soil so as to promote microbial activity, the percolation rate could be expected to decrease rapidly but upon drying, followed by the reapplication of water, the percolation could be expected to be at a higher rate than the initial run. This action has occurred on field test ponds and will be discussed later.

The San Joaquin Valley Project.—The research program described in this paper has concentrated on checking some of the foregoing conclusions under field conditions and developing some practical method of maintaining the peak rates or stimulating percolation during the entire run. Sterilization of soil and water is, of course, an impossibility under field conditions.

An intensive series of field experiments was started in 1944. A group of 9 test ponds, originally started in 1936 by the North Kern Water Storage District was put into operation and 37 others were constructed. Fifteen of these ponds were in isolated locations along the approximate line of the Friant-Kern Canal. These ponds were located on different soil types and served from different water supplies. The remaining ponds were located in two groups on the two predominant soil types of the Kern area. A six-acre tract was leveled and prepared for experimental work and was so laid out that the water could be spread in a thin sheet instead of by ponding. Results of some of the small test ponds indicated this might be the proper method of spreading, particularly if vegetation is used to promote percolation. In addition, records were made available by the North Kern Water Storage District of spreading tests on 17 areas, ranging in size from a few acres to over 50 acres.

Practically all of the experimental field work has been confined to two groups of ponds in Kern County, one near Wasco, located on Hesperia sandy loam formation, and the other near Minter Field, located on Exeter sandy loam. By confining the tests to these groups, the differences in quality of the water supplying the ponds, soils, and other factors have been eliminated to a large extent, and various treatments of soil and water can be tried and compared with control ponds. It should be borne in mind that these small test ponds are intended to give only relative rates between different soil and water treatments, and the percolation rates are not necessarily applicable to large-scale spreading areas.

Treatment of Test Ponds

The test ponds were subjected to a variety of treatments. These included different cultural treatments, mulches, various grasses, chemical treatments, and different methods of operating with alternate wet and dry periods and shallow, deep, and fluctuating water depths. The effects of all treatments were checked against the rates obtained from undisturbed control ponds. Some of the experiments were not considered practical on a large scale but were of an academic nature, though important in the search for practical solution of the percolation problem.

The field treatments attempted fall under one of five general classes: (*a*) Chemical; (*b*) mechanical; (*c*) vegetative; (*d*) operational procedures; and (*e*) addition of organic matter.

(*a*) *Chemical.*—The immediate concern in connection with the effect of chemical treatment on percolation rates is the characteristics of the water supply. Ordinarily, in water spreading there is no choice of water, but its suitability for spreading should be examined as far as available knowledge permits. Considerable information exists as to the effects of certain types of water on the percolation rates consequent to irrigation, and these effects in general are believed to apply to spreading.

It is common knowledge that hard water is more conducive to rapid infiltration than soft water. Water that is relatively high in calcium and magnesium is called hard, and water low in these elements is called soft. Ordinarily, water analyzing below 30 ppm of calcium and magnesium is considered soft, from 30 to 60 ppm fairly hard, and above 60 ppm hard.

Sodium is another element known to affect the movement of water into or through a soil. Its importance lies not so much in the quantity present, but in its relation to the elements calcium and magnesium. The sodium percentage, calculated by dividing the quantity of sodium by the sum of the quantities of calcium, magnesium, sodium, and potassium (all in equivalents per million), is the usual way to classify the quality of water for irrigation with respect to the sodium effect on the soil. A water of high sodium percentage tends to deflocculate the colloidal soil particles and consequently hinders the movement of water. As is the case with hardness, no inflexible distinction can be drawn between a good and a poor quality of water. Generally, water in which the sodium percentage is above 65% is considered to be of poor quality, between 50% and 65% the quality is questionable, and below 50% it is satisfactory both for irrigation and for spreading.

The waters that are of primary interest in this study are those of the San Joaquin River, to be delivered through the Friant-Kern Canal of the Central Valley Project, and that of the Kern River. Both have water of low total salt content. The conductance of Friant-Kern Canal water is less than 10. The sodium percentage of 38.4 is considered to be satisfactory for spreading, but the water definitely falls into the class of a soft water with respect to calcium carbonate and, therefore, is not of the best quality from a water-spreading point of view. Kern River water has a conductance of about 25. The hardness is fair, being around 50 ppm. The sodium percentage varies considerably from maximums of 70 to minimums of about 30 and averages

about 50. Surface storage is proposed for Kern River, and it is not known what effect, if any, this storage will have on the water quality.

For the isolated ponds along the line of the Friant-Kern Canal, the waters used for testing differed materially. Some of these waters were classed as good and some as unsatisfactory. At one pond, the soil was a loamy sand and from all appearances should have taken water at a rapid rate. However, the water supply was wholly unsatisfactory, as the sodium percentage was 96 and the hardness 12.7 ppm. As a result, the percolation rate decreased to only a few hundreths of a foot per day after a few weeks' application of water. The variation in the quality of the water supplying these isolated ponds was one reason for their discontinuance.

In view of the known effects of water quality on percolation rates, several experiments were made at the Minter Field and Wasco test ponds to determine the effect and practicability of undertaking soil or water treatment to lower the sodium percentage or raise the hardness. Applications of gypsum ($Ca\,SO_4$) and calcium chloride ($Ca\,Cl_2$) were beneficial and increased percolation rates, but only temporarily. Fig. 3 illustrates the results obtained by the use of gypsum and calcium chloride.

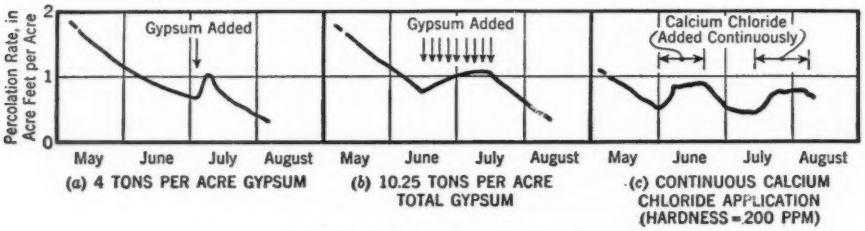

FIG. 3.—EFFECT OF TREATMENT ON PERCOLATION RATE

Other chemical tests included the application of lime to increase the water hardness and copper sulphate for algae control. Some of these tests were not conclusive in so far as their intended purposes were concerned. No tests were made to determine whether or not the soil or water was affected by the addition of the chemicals since the result was read only in the effect on the percolation rate.

(*b*) *Mechanical.*—The treatments classed as mechanical involved spading of the soil, removal of the top soil, raking or scraping of the soil surface, sinking of auger holes backfilled with gravel, and covering of a pond with a tar-papered roof to exclude sunlight.

Sod removal, with and without spading, was found to be detrimental to percolation. Spading or plowing alone prior to the application of water appears to be beneficial at the Wasco Ponds, but is of questionable value at Minter Field. After a prolonged period of spreading, initial percolation rates could be recovered only by allowing the soil to dry and then breaking it up by spading or plowing.

Raking or scraping off the top $\frac{1}{4}$ in. or $\frac{1}{2}$ in. of soil surface apparently had no effect. During nearly all spreading runs, numerous bubbles (air or other gas) were noted on the soil surface. Removal of these bubbles by daily raking

had no apparent effect. There are several theories as to what these bubbles contain, how they are formed, and what their effect on percolation might be, but unfortunately there has been no opportunity to investigate them thoroughly. One sample was analyzed as air, although other casual inspections indicated carbon dioxide and marsh gas. It is entirely possible and perhaps probable that the bubbles contain entirely different gases at the start of a run and at the end, which might be six months later. The bubbles seem to be more numerous on some days and in some ponds than on other days and in other ponds. The presence of these bubbles may or may not play an important part in the study of the soil microbiology.

Evidence obtained in the laboratory on soil cores and in the field with tensiometers shows that the percolation rate decrease is caused by changes that take place at the soil surface and in the topsoil containing, among other things, organic matter. Auger holes were drilled and backfilled with gravel to by-pass the surface soil. This treatment apparently has some merit as beneficial results were obtained at Minter Field. The effects at Wasco are questionable. This is to be expected, as a sand stratum exists at Minter Field that is penetrated by the auger holes. The soil is more uniform and no such sand stratum exists at the Wasco ponds.

Because prior research[2] had indicated that the rates during an early part of the spreading run were affected by air entrapped in the soil, an attempt was made to hasten its removal. Four auger holes were drilled to a depth of 20 ft in a test pond. The holes were backfilled with gravel to within 1 ft of the surface, and this last foot was filled with tamped earth. Vents, consisting of $\frac{3}{4}$-in. pipe, extended from the gravel fill above the water surface. The treatment was not effective. A 1944 report[3] also found that it was not possible to drive all the air from the soil by slowly saturating the soil column from the bottom upward or by applying water at the top. The air entrapped in the soil was removed by being dissolved in the water passing through the soil. If this conclusion is correct, the use of vents with auger holes was, of course, doomed to failure.

As a further test of algae control, one pond was covered with a tar-papered roof so as to exclude all sunlight. No effect was noted on the percolation rates.

(*c*) *Vegetative.*—Trials with vegetation were made for two purposes: (1) to increase or maintain percolation rates; and (2) to find a grass or plant that would survive on water-spreading areas and provide a cash or forage crop.

Due to the high cost of spreading, it is highly desirable to derive some productive use from the land other than spreading. The best possibility is believed to be the raising of hay or grazing crops. The conditions to be met by a grass or another plant in the San Joaquin Valley are severe. Spreading will normally occur in the late winter and spring months, although in wet years the period might be prolonged considerably. In drought years there will not only be no water to spread, but no water available to irrigate the grasses or plants to sustain them on a spreading area. Normally there will be drought periods of several months each year, extending through the summer and fall. The

[3] "Effect of Microorganisms on Permeability of Soil Under Prolonged Submergence," by L. E. Allison, *Soil Science*, Vol. 63, No. 6, June, 1947.

grass or plant desired is, therefore, one that will grow under several months of constant wetting, survive the long, hot, dry summers, and provide a hay or forage crop. In order to avoid artificial reseeding, perennial plants or those that reseed or grow voluntarily are desirable.

Several grasses and other plants were tried. These were, in general, native to the area and grew under the conditions set forth above. Highly pestiferous plants, such as Johnson grass (Sorghum halepense), were not considered. Bermuda grass appears to have the greatest possibility. It grew luxuriantly under prolonged wetting, provided the tops were not submerged, but died under total submergence. Bermuda grass survived long drought periods and furthermore is considered a good grass for grazing lands. There is evidence that after it had become well established it improved the ability of the soil to take water.

Paragrass also grew luxuriantly under spreading conditions, but its value as a forage crop is not definitely known. A very dense growth was obtained, but apparently it does not withstand freezing temperatures, as the tops froze back to the soil or water surface each winter. Volunteer growth appeared in the following spring, however.

Dallis grass (considered a pest in some parts of the valley owing to its tendency to grow in irrigation ditches), Rhodes grass, rye grasses, salt grass, Sudan grass, and bluestem were all tried, but none appeared to have the possibilities of Bermuda grass. Bermuda grass, considered a pest or weed in cultivated crops, is quite common throughout the San Joaquin Valley. Its value as a pasture, however, renders it satisfactory on a spreading area. In fact, any other grass planted on a spreading area would apparently have a difficult time to escape being crowded out by Bermuda grass.

Button willow shrubs (baccharis glutinosa) were planted and grown successfully in two ponds, but no effect on the percolation rate could be noted. As far as is known, they have little forage or other value. They were found growing wild on the large spreading areas of southern California.

Alfalfa failed on soil wet continuously for a 10-day period and then dried 10 days, and the rate of percolation was not benefited by its use.

(*d*) *Operational Procedures.*—Under this classification are included the experiments with different depths of water, different lengths of drying periods between runs, cessation of water application before the percolation rate reaches a minimum, and the desilting of the water supply.

As would be expected, the percolation rate varies directly with changes in the depth of water or head during a spreading run. However, if a spreading run is started and maintained at a shallow depth (0.2 or 0.3 ft) throughout a run, the percolation rates tend to be higher and maintain themselves better than when the water is applied at depths of 1 or 2 ft. This variation may be caused by differences in sumlight reaching the soil, temperature, or other factors. It is also well established by these tests that certain plant growths will thrive with the shallow depths of water, whereas they are drowned out under the greater depths.

The effect of interruptions of spreading apparently depend largely on the degree of drying that takes place in the topsoil. Short interruptions (of a

few days or less) usually have only a temporary effect on the percolation rate, and after a few days the rates appear to return to what would have been expected had no interruptions occurred. It is believed that air entering the soil during a short interruption in spreading causes the temporary changes in percolation rate upon restarting.

Interruptions of such duration that the topsoil dries usually cause an increase in percolation rates, and in some cases have resulted in a rate recovery equal to the initial rate. Usually, however, the rates during the second run were somewhat smaller than the initial rates, although the shapes of the curve were similar, as previously mentioned and illustrated in Fig. 1. Soil samples were taken during all off periods, and the degree of drying of the top 6 in. of soil was recorded. Tests were made to determine the effect of drying the soil to a 10% soil moisture content, as compared with a 5% soil moisture, but other uncontrolled factors made it impossible to draw any definite conclusions. The field capacity of the top 6 in. of soil at Wasco is approximately 11.5% and the wilting point 5.5%. At Minter Field, the field capacity is 8.7% and the wilting point 3.3%. During the summer, the surface soil dries rapidly, and percentages of 10 or lower can be obtained in a relatively short time (two or three weeks). During the winter months, showers and cool foggy weather usually prevent the top soil from drying below 10% at any time.

Desilting of the water at Minter Field was attempted by passing the water from one pond through another pond to allow settling. No effect on the percolation rate was noted. Tests to determine whether or not the water was actually desilted were not made, so the results are inconclusive.

(*e*) *Addition of Organic Matter.*—The addition of organic matter was tested on several ponds. In some cases the results were remarkable, and percolation rates were increased several times over the rate obtained on undisturbed soils. Of all the materials applied, cotton gin waste was found to give the best results. Alfalfa hay applied at the rate of 5 or 10 tons per acre gave temporarily beneficial results. Barley, Sudan grass, Paragrass, and Dallis grass that were grown to maturity and then spaded under or cut and allowed to lie on the ground, gave indications of being beneficial in some cases, but the results were insignificant in most instances. Cornstalks at field run, spaded under with and without ammonium sulphate, were tried. The cornstalks applied with ammonium sulphate resulted in a high peak percolation rate; but the high rates were of short duration, and a fairly rapid decline in rate followed the peak. Barnyard manure applied at 8 tons per acre had no noticeable effect on the percolation rate.

Cotton gin waste, consisting of boll hulls, leaves, stems, a few seeds and a small amount of lint resulted in substantially increased percolation rates in every trial. Unfortunately, no measurement of the amount of material when first applied was made, other than to record it as a 6-in. layer. Three different methods of application were tested: (1) The waste in a trial was added to the soil surface or merely added to a pond during spreading operations; (2) the material was spaded under, then kept moist for 30 days by frequent irrigations or continual submergence. At the end of the 30-day period the soil was permitted to dry to 10% moisture or less before the spreading. This

30-day moist or wet period was called an incubation period that is believed to start or hasten the process of decomposition; and (3) the cotton gin waste was spaded under immediately prior to spreading.

In the first and third methods, the results were highly beneficial, but the effect was delayed for several weeks or more before it became apparent. By the second method (spading the gin waste material into the soil and then giving a 30-day incubation period, followed by a drying-out period before spreading) increased percolation rates were obtained almost immediately.

In addition to the increased percolation rates, the long-lasting effect of an application of cotton gin refuse is of prime importance. Applications made in 1946 were still apparently highly effective in 1950. It is true that percolation rates fluctuate from high peaks and decline to relatively low rates, but in every case in which the gin refuse had been previously applied, high percolation rates were recovered upon drying and spading. The rates during spreading reached peaks of 14 ft per day and leveled off at 4 to 5 ft per day and declined to a few hundreths of a foot per day after a run of several weeks (Fig. 4).

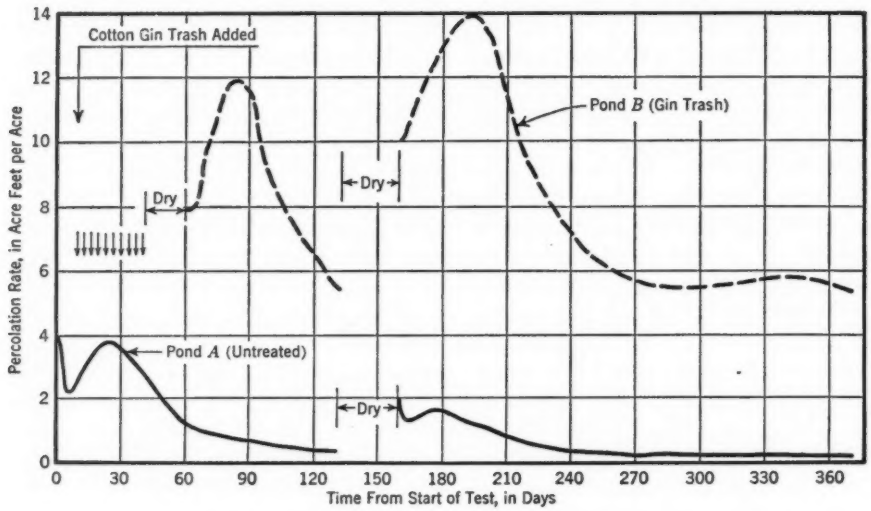

FIG. 4.—EFFECT OF COTTON GIN TRASH ON PERCOLATION RATE

The behavior of the gin-trash treated ponds ties in closely with experiments that demonstrated in the laboratory that microbiological activity causes the decrease in percolation rates under prolonged submergence.[4] The gin trash provides food for the soil microorganisms or perhaps food for certain types of organisms. The residues left during decomposition of the gin trash causes rapid sealing of the soil, but in turn tends to improve the soil aggregation and upon drying, the percolation rates are improved materially.

[4] "Report for 1944 Laboratory Phases of Cooperative Water Spreading Study," by J. E. Christiansen and O. C. Magistad, U. S. Dept. of Agriculture, Regional Salinity Laboratory, Bureau of Plant Industry, Soils and Agriculture Engineering, Washington, D. C., 1944.

Laboratory Work

There are many phases of the water-spreading problem that cannot be worked out under field conditions. A pond may respond to a certain treatment, but the reason for such response cannot be determined without laboratory investigation. Because of the outstanding results obtained in the field with cotton gin trash, the laboratory work is important in that phase of treatment. While gin trash is available in San Joaquin Valley, it is at present expensive to apply to large areas. Also, spreading is needed in other areas in which gin trash is not available, and it is felt that if more information is obtained on why this treatment promotes percolation, it will be possible to assist in those areas. The feeling is that the gin-trash treatment is possibly a very important and significant solution to the problem of percolation under prolonged wetting.

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